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(71) Applicant: CANON KABUSHIKI KAISHA
30-2, 3-chome, Shimomaruko, Ohta-ku
Tokyo(JP)

(72) Inventor: Kuroda, Ryo, c/o Canon Kabushiki Kaisha
30-2, 3-chome, Shimomaruko
Ohta-ku, Tokyo(JP)
Inventor: Yamano, Akihiko, c/o Canon Kabushiki Kaisha
30-2, 3-chome, Shimomaruko
Ohta-ku, Tokyo(JP)
Inventor: Nose, Hiroyasu, c/o Canon Kabushiki Kaisha
30-2, 3-chome, Shimomaruko
Ohta-ku, Tokyo(JP)
Inventor: Miyazaki, Toshihiko, c/o Canon Kabushiki Kaisha
30-2, 3-chome, Shimomaruko
Ohta-ku, Tokyo(JP)
Inventor: Oguchi, Takahiro, c/o Canon Kabushiki Kaisha
30-2, 3-chome, Shimomaruko
Ohta-ku, Tokyo(JP)

(74) Representative: Blumbach Weser Bergen Kramer Zwirner Hoffmann Patentanwälte
Radeckestrasse 43
W-8000 München 60(DE)

(54) Information recording and/or reproducing apparatus.

(57) Apparatus and method for recording and/or reproducing information onto/from a medium through a probe electrode by using a scanning tunnel microscope comprises: a voltage applying circuit to apply a voltage between the medium and the probe electrode, in which the recording operation and/or the reproducing operation of the information onto/from the medium are/is executed by applying the voltage by the voltage applying circuit; a distance adjusting mechanism to adjust a distance between the medium and the probe electrode in a manner such that the voltage applied by the voltage applying circuit and the current flowing between the medium and the probe electrode to which the voltage has been applied by the voltage applying circuit satisfy the current-voltage characteristics such that the current between the medium and the probe electrode also changes in accordance with a change in the applied voltage.

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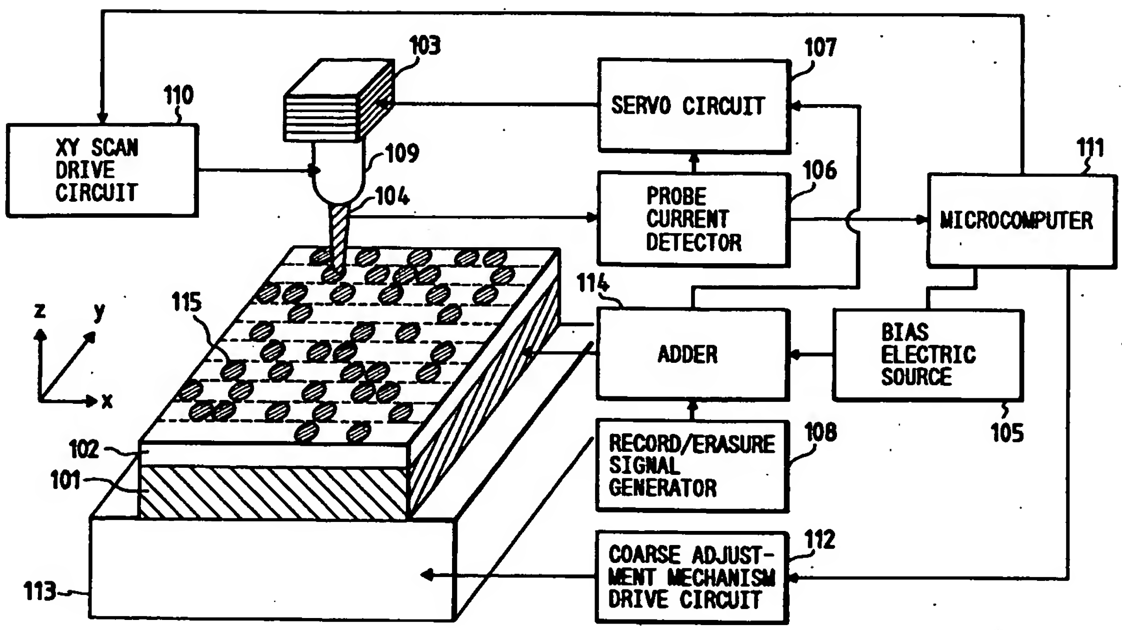
FIG. 1


103
107
110
SERVO CIRCUIT
XY SCAN DRIVE CIRCUIT
109
111
104
106
PROBE CURRENT DETECTOR
MICROCOMPUTER
114
115
z
y
x
ADDER
BIAS ELECTRIC SOURCE
102
RECORD/ERASURE SIGNAL GENERATOR
108
105
101
112
COARSE ADJUSTMENT MECHANISM DRIVE CIRCUIT
113

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to an apparatus for recording and/or reproducing.

Particularly, the invention can be suitably used in apparatus and method for recording and/or reproducing to which a technique such as a scanning tunnel microscope or the like has been applied.

Description of the Related Background Art

In recent years, application of memory materials is a main stream in electronics industries such as computer and its related apparatus, video disc, digital audio disc, and the like. Development of the memory materials is also extremely actively being performed. Although the performances which are required for the memory material differ depending on the applications, in general, the following points can be mentioned: (1) a density is high and a recording capacity is large; (2) response speeds for recording and reproducing are high; (3) an electric power consumption is small; (4) a productivity is high and a price is low; and the like.

Hitherto, a semiconductor memory using a semi-conductor as a raw material and a magnetic memory using a magnetic material as a raw material are main memories. In recent years, however, in association with the advancement of the laser technique, a cheap recording medium of a high density by an optical memory using a thin organic film such as organic coloring matter, photo polymer, or the like has been proposed.

On the other hand, recently, a scanning tunnel microscope (hereinafter, abbreviated to an "STM") which can directly observe an electron structure of a surface plane atom of a conductor has been developed [G. Binnig et al., "Phys. Rev. Lett.", 49,57 (1982)], so that a real space image can be measured at a high resolution irrespective of a monocrystal and an amorphous. Moreover, the STM also has an advantage such that a sample can be observed with a low electric power without giving a damage to the sample by a current. Further, the STM can also operate in the atmosphere and can be used for various kinds of materials. Therefore, applications of a wide range of the STM are expected.

The STM uses a principle such that when a bias voltage is applied between a probe (probe electrode) of a metal and a conductive substance and the probe is allowed to approach until a distance of about 1 nm, a tunnel current flows. The tunnel current is very sensitive to a change in distance between them. By scanning the probe so as to keep the tunnel current constant, various information regarding a whole electron cloud of a real space can be also read. At this time, a resolution in the in-plane direction is equal to about 0.1 nm.

Therefore, by applying the principle of the STM, the recording and reproduction at a high density can be sufficiently performed on the atom order (sub-nanometer). For instance, in the recording/reproducing apparatus disclosed in JP-A-61-80536, atomic particles adsorbed onto the medium surface are eliminated by an electron beam or the like and the writing operation is executed and the data is reproduced by the STM. Further, there have been proposed methods whereby the recording and reproduction are executed by the STM by using a thin film layer as a recording layer made of a material such as π electron system organic compound or chalcogen compound class having a memory effect for a switching characteristic of a voltage current (JP-A-63-161552, JP-A-63-161553). According to the above methods, assuming that a recording bit size is equal to 10 nm, the recording and reproduction of a large capacity of 10^{12} bits/cm^2 can be performed.

SUMMARY OF THE INVENTION

The invention is an applied invention of the foregoing conventional example. It is the first object of the invention to provide recording and/or reproducing apparatus and method in which the recording and/or reproduction can be efficiently performed without a fear of damages of a probe tip and a recording medium.

The above and other objects and features of the present invention will become apparent from the following detailed description and the appended claims with reference to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a block diagram showing a construction of a recording and/or reproducing apparatus according to an embodiment of the invention;

Fig. 2 is a block diagram showing the details of a servo circuit in Fig. 1;
Figs. 3A, 3B, 4A, and 4B are explanatory diagrams showing a control method of a probe electrode upon recording in the conventional example;
Fig. 5 is an explanatory diagram showing a control method of a probe electrode upon recording in the apparatus of Fig. 1;
Fig. 6 is an explanatory diagram showing an example in another medium of a control method of a probe electrode upon recording in the invention;
Fig. 7 is an explanatory diagram showing a control method of a probe electrode upon reproduction in the apparatus of Fig. 1; and
Fig. 8 is an explanatory diagram showing another example of a control method of a probe electrode upon reproduction in the invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Fig. 1 is a diagram showing a recording and/or reproducing apparatus according to a preferred embodiment of the invention.

As shown in the diagram, the recording/reproducing apparatus comprises: a probe electrode 104 which is arranged such that a tip of the probe electrode is close to the surface of a recording medium 102; a bias electric source 105 as means for applying a voltage between a substrate electrode 101 arranged on the back surface of the recording medium 102 and the probe electrode 104; a record/erasure signal generator 108; an adder 114 for adding outputs of the bias electric source 105 and the generator 108 and for applying between the electrode 104 and the medium 105; a probe current detector 106 to detect a current flowing between the recording medium 102 and the probe electrode 104; a longitudinal direction driving mechanism 103 for driving the probe electrode in the longitudinal direction (Z direction) to fluctuate a distance between the probe electrode 104 and the recording medium 102; and a servo circuit 107 to output a control signal to drive the longitudinal direction driving mechanism 103 on the basis of the voltage applied by the voltage applying means and the current detected by the probe current detector 106 in a manner such that a current which is equal to a value of the current flowing for the applied voltage flows between the probe electrode 104 and the recording medium 102 in the case where the distance between the probe electrode 104 and the recording medium 102 is set to be constant. The recording medium 102 and the substrate electrode 101 are held on a coarse adjustment mechanism 113. By driving the coarse adjustment mechanism 113 through a coarse adjustment mechanism drive circuit 112 by a microcomputer 111, the recording medium 102 is relatively moved for the probe electrode 104.

An epitaxial growth plane of gold or a graphite cleavage plane on a flat substrate made of a glass or mica or the like can be used as a substrate electrode 101. Squarilium-bis-6-octyl azulene (hereinafter, abbreviated to "SOAZ") is used as a recording medium 102. A built-up film of two layers of monomolecular films is formed on the surface of the substrate electrode 101 by a Langmuir-Blodgett's technique.

As a probe electrode 104, it is possible to use an electrode which is obtained by electrolyte polishing a tungsten line or the like or by mechanically cutting a platinum line or the like and whose tip is sharp (radius of curvature is less than 1 μm) and which is conductive.

A PZT device or the like is used as a longitudinal direction driving mechanism 103, a bias voltage of about 1 V is applied between the substrate electrode 101 and the probe electrode 104 by the bias electric source 105, and a probe current flowing between them is detected by the probe current detector 106.

Fig. 2 is a block diagram of the servo circuit 107.

In the diagram, reference numeral 801 denotes a preset current value calculation circuit to calculate a set current value I_0 for an applied bias voltage value V and a distance set value Z_0. A calculating method in the above case differs depending on current-voltage characteristics between the probe electrode 104 and the substrate electrode 101. For instance, when a tunnel current characteristic or a field emission current characteristic is exhibited, the set current value I_0 is calculated by the following equations.

$$I_0 = \frac{A \exp(-BZ_0)}{Z_0} V \quad \ldots\ldots (1)$$

(tunnel current characteristic)

$$I_0 = C(\frac{V}{Z_0})^2 \exp(\frac{-DZ_0}{V}) \quad \ldots\ldots (2)$$

(field emission current characteristic)

Where, A, B, C, D denote constants which are predetermined by substances constructing the electrode and the recording medium.

In more general, assuming that an interval between the probe electrode and the substrate electrode is set to Z, the set current value I_0 is calcualted in accordance with the following equation

$I_0 = f(V, Z_0)$

so long as the current (I) - voltage (V) characteristics are expressed by $I = f(V, Z)$.

Reference numerals 802 and 803 denote function conversion circuits for obtaining signals logI and logI_0 by, for instance, logarithm converting a detection probe current value I and the set current value I_0, respectively; 804 a subtracter for calculating a difference (logI - logI_0) between those signals and for outputting; 805 and 806 denote a filter and an amplifier (gain G) for an output of the subtracter 804. A signal G(logI - logI_0) which is generated from the amplifier 806 is supplied to the longitudinal direction driving mechanism control means 103. The sign of the gain G by the amplifier 806 is selected so as to drive in such a direction that the probe electrode 104 is away from the substrate electrode 101 when I I_0 and that the probe electrode 104 contrarily approaches the substrate electrode 101 when $I < I_0$. Due to this, the probe current value I is controlled so as to be always equal to the set current value for the applied bias voltage V. By controlling as mentioned above, even if the applied bias voltage V is changed as will be explained hereinlater, a resistance characteristic between the electrodes 101 and 104 is not changed, so that the distance between the probe electrode 104 and the substrate electrode 101 can be held constant.

Since I_0/V is a constant in the case of the equation (1), the execution of the above control according to the equation (1) is equivalent to that a control to make I_0/V constant is executed.

The tracking control by the probe electrode 104 is performed by driving the probe electrode 104 by the microcomputer 111 through an XY scan drive circuit 110 on the basis of the output of the probe current detector 106. The bias electric source 105 is also controlled by the microcomputer 111.

The recording/erasing operations will now be described.

First, the probe electrode 104 is driven by the longitudinal direction driving mechanism 103 so as to approach a desired position of the recording medium 102 until a distance of about sub-nanometer. Subsequently, a signal from the record/erasure signal generator 108 is applied between the substrate electrode 101 and the probe electrode 104 through the adder 114. The recording/erasing operations are executed at a desired position of the recording medium 102 which is close to the tip of the probe electrode 104. In a manner similar to the above, upon reproduction, a bias voltage for reading is applied between the substrate electrode 101 and the probe electrode 104 by the bias electric source 105 and the reproducing operation is executed at a desired position of the recording medium 102 which is close to the tip of the probe electrode 104.

Practically speaking, a reading voltage of 1 V as a voltage which doesn't exceed a threshold voltage which causes an electrical memory effect was applied between the probe electrode 104 and the substrate electrode 101 and the current value was measured. Thus, the off state was exhibited at a current value of 10^{-11} A or less. Subsequently, a triangular wave pulse voltage which is equal to or higher than a threshold voltage V_{th} which causes an on state was applied and, thereafter, a voltage of 1 V was again applied for reproduction and the current value was measured. Thus, the current of about 10^{-7} A flowed and the on state was observed. That is, the on state was recorded. Subsequently, an inverse triangular wave pulse voltage which is equal to or higher than the threshold value which causes a transition from the on state to the off state was applied and, thereafter, a voltage of 1 V was again applied for reproduction. Thus, the current value at this time was equal to or less than 10^{-11} A and it has been confirmed that the state is returned to the off state.

The control of the position in the longitudinal direction of the probe electrode upon recording/reproduction will now be described with reference to Figs. 3A and 3B to 8.

A comparison example for the embodiment will now be explained.

With respect to a method of controlling the distance between the probe electrode and the recording medium in the recording/reproducing method, there are the following methods: a method whereby the recording/reproducing operations are executed while controlling the distance so as to make the probe current constant; a method whereby a current mean value which is obtained by averaging the current values which change due to the presence or absence of the recording is used as a reference and the distance is controlled so as to obtain such a reference value; and a method whereby upon recording, a mean value of the current at a time point before the current is enhanced for recording is held as a reference value and the distance is controlled so as to obtain such a reference value.

Figs. 3A and 4A relate to the former case. Figs. 3B and 4B relate to the latter case. Figs. 3A and 3B show the case of the medium in which the recording is performed by a change in resistance value. Figs. 4A and 4B show the case of the medium in which the recording is executed by a change in shape. Each diagram shows a state when the applied voltage between the electrodes 101 and 104 has sequentially been increased from the left.

In the above methods, however, according to the method whereby the distance is controlled so as to make the probe current constant upon recording, as shown in Figs. 3A and 4A, the distance between the probe electrode 104 and the recording medium 102 or a conductive recording medium 402 increases in a process to increase the applied voltage V in order to perform the recording operation to the recording medium 102 or 402 and the electric field and potential decrease by an amount corresponding to the increase in distance. Therefore, there are problems such that the voltage is not efficiently applied and that a recording bit diameter increases because the voltage is applied in a wide range in correspondence to the increase in the distance.

On the other hand, according to the method whereby the distance is controlled so as to keep the position before the recording upon recording, as shown in Figs. 3B and 4B, there is a problem such that when the resistance value or surface shape of the recording portion has changed, a large current flows, so that the tip of the probe and the medium in the recording portion are damaged.

Fig. 5 is an explanatory diagram of a method of controlling the position in the longitudinal direction of the probe electrode 104 upon recording. Fig. 5 shows the control method in a manner similar to Figs. 3A and 3B. In the process to increase the applied voltage V from V_0 ($V < V_{th}$) in order to record, the distance between the probe electrode 104 and the substrate electrode 101 is held constant by the control of the longitudinal direction driving mechanism 103 by the servo circuit 107. Thus, since the electric field and the potential are effectively applied to the recording medium 102, the electrical memory effect can be caused by a lower applied voltage (for instance, the threshold voltage V_{th}) without losses of the electric field and potential due to an increase in distance between the probe electrode 104 and the substrate electrode 101 in association with an increase in applied voltage V, such losses cannot be avoided by the control to make the probe current I constant as mentioned above. The recording bit diameter also decreases because the distance between the probe electrode 104 and the substrate electrode 101 doesn't increase.

The recording is executed by the applied voltage ($V > V_{th}$) exceeding the threshold voltage V_{th}. When a resistance value R_{OFF} in the off state of a recording portion 115 changes (decreases) to a resistance value R_{ON} in the on state, the distance between the probe electrode 104 and the substrate electrode 101 increases until a distance at which a resistance value R of the gap between the probe electrode 104 and the substrate electrode 101 is equal to $R_{ON} + R_T$ ($= R_{OFF}$). Due to this, the recording is executed without causing a large current to flow between the probe electrode 104 and the substrate electrode 101. Damages of the tip of the probe electrode 104 and the medium of a recording portion 201 can be prevented.

Fig. 7 is an explanatory diagram of a method of controlling the position in the longitudinal direction of the probe electrode upon reproduction. The substrate electrode 101 is constructed by an atom array of a conductive crystal cleavage plane or the like and has a periodic structure on the surface. The bias electric source 105 is constructed in a manner such that when the recording state of the recording medium 102 on the substrate electrode 101 is reproduced by scanning the probe electrode 104, a bias electric source 604 for reproducing and a bias electric source 605 for tracking are alternately switched by a bias voltage switching circuit 606 in accordance with a switching signal from a reproduction/tracking switching signal generator 607 and the switched source is used. That is, the recording state is reproduced by the bias for reproducing and the periodic structure of the surface of the substrate electrode 101 is detected by the bias for tracking, thereby executing the tracking control. At this time, by controlling the position in the longitudinal direction of the probe electrode 104 in a manner such that the probe current value is always equal to the set current value for the applied bias voltage, a change in distance between the probe

electrode 104 and the substrate electrode 101 due to the switching of the bias voltage is eliminated. The longitudinal direction position control amount of the probe electrode 104 directly reflects the recording state and the periodic structure for tracking.

The operation of the embodiment will now be summarized below. In the construction of the embodiment, when a voltage signal which is equal to or higher than a predetermined threshold level which causes the memory effect in the recording medium is applied, a change in electrical characteristic and physical and chemical changes occur in the recording medium portion, so that information is recorded in this portion. Before the memory effect is caused, the distance between the probe electrode and the recording medium is controlled in a manner such that a current which is equal to the value of current flowing for the applied voltage in the case where the distance between the probe electrode and the recording medium is made constant flows between the probe electrode and the recording medium. Therefore, the distance between the probe electrode and the recording medium is held constant even if a voltage fluctuation of the threshold level or less occurs. When the memory effect is caused, the resistance value between the probe electrode and the recording medium decreases due to the change in electrical characteristics and the physical and chemical changes by such a memory effect. Therefore, under the control as mentioned above, the distance between the probe electrode and the recording medium increases by only a supplementary amount of such a decreased amount.

On the other hand, even under the constant applied voltage which is equal to or lower than the threshold level, the distance between the probe electrode and the recording medium is held constant under the foregoing control. When the information recording portion on the recording medium arrives to a position under the probe electrode, in a manner similar to the above, the resistance value between the probe electrode and the recording medium decreases and the distance between the probe electrode and the recording medium is controlled so as to increase by only a supplementary amount of such a decrease amount. That is, a control amount in the above case indicates the recorded information, thereby executing the reproduction.

In any of the recording and reproducing operations, the distance between the probe electrode and the recording medium is set to an enough small value and is held constant excluding the recording information portion by the foregoing control and the electric field between the probe electrode and the recording medium is stably held. Therefore, the recording and reproducing operations are efficiently executed at a high S/N ratio and a low error ratio by the stable electric field and by a small recording bit diameter. In the recording information portion, since the distance between the probe electrode and the recording medium is controlled so as to increase, the recording and reproducing operations are executed without causing no damage of the probe electrode and the recording medium due to an excessive current flowing between them.

Fig. 8 is an explanatory diagram of another embodiment of a method of controlling the position in the longitudinal direction of the probe electrode upon reproduction. A DC bias by a DC bias electric source 704 is modulated by a bias modulating circuit 705 and a resultant modulated bias is used as a bias for reproduction. Only the modulation component in a reproduction probe current signal I_p derived is extracted by a synchronous detection circuit 706. By such a method, the noises in the reproduction signal is reduced and the detection of the recording state by a spectroscopic method (information regarding an electron state is obtained from a dI_p/dV signal) is executed.

In the above case as well, as mentioned above, the position control in the longitudinal direction of the probe electrode 104 is executed in a manner such that the probe electrode current value I_p is always equal to the set current value for the applied bias voltage V. Thus, a fluctuation of the distance between the probe electrode 104 and the substrate electrode 101 due to the modulation of the bias voltage doesn't occur. The control amount of the position in the longitudinal direction of the probe electrode 101 directly reflects the recording state.

As a practical example of the position control in the longitudinal direction of the probe electrode 104 according to the invention, explanation has been made above with respect to the examples of the bias change for tracking, noise reduction, and detection of the recording state by the spectroscopic method. However, the concept of the invention is not limited to the above examples but widely intends to keep the distance between the probe electrode and the substrate electrode constant for a bias change.

Although the example of the electrical memory effect of the thin organic film has been mentioned above as a recording medium and a recording method, the concept of the invention is not limited to such an example. It is also possible to construct in a manner such that a voltage which is equal to or higher than a certain threshold value is applied to the conductive recording medium 402 having a flat surface as shown in Fig. 6, thereby locally changing the surface shape of the recording medium 402 into a concave/convex shape by fusion, evaporation, decomposition, compound, or change in orienting direction. Fig. 6 shows in a

manner similar to Figs. 4A and 4B. The effect of the invention will be obviously understood from Fig. 6. For instance, in the case of the method whereby the recording is executed by forming a concave/convex shape onto the surface, the following materials can be mentioned: an HOPG (Highly-Oriented-Pyrolytic-Graphite) cleavage substrate; an Si wafer; a thin metal film of Au, Ag, Pt, Mo, Cu, etc. which has been evaporation deposited in a vacuum state or which has been epitaxially grown; and glass metal of $Rh_{25}Zr_{75}$, $Co_{35}Tb_{65}$, or the like. In the case of the method whereby the recording is executed by the electron state of the surface, a thin film layer of amorphous Si, organic compound of the π electron system, or chalcogen compound class and the like can be mentioned.

It will be obviously understood that the above embodiment is also applied to an apparatus which executes only either one of the recording and reproducing operations.

As described above, according to each of the above embodiments, even if the applied voltage is changed, the distance between the probe electrode and the recording medium can be adjusted. Therefore, there are the following effects: (1) the recording signal can be efficiently applied; (2) the recording bit diameter can be reduced; (3) the damages of the tip of the probe and the medium of the recording portion upon recording can be prevented; and (4) various reproducing methods of applying the modulation to the bias such as tracking, improvement of an S/N ratio, spectroscopic method, etc. can be stably realized.

Claims

1. An apparatus for recording and/or reproducing information onto/from a medium through a probe electrode, comprising:

   voltage applying means for applying a voltage between the medium and the probe electrode, in which the recording operation of the information onto the medium and/or the reproducing operation of the information from the medium are/is executed by applying the voltage by the voltage applying means; and

   distance adjusting means for adjusting a distance between the medium and the probe electrode in a manner such that the voltage applied by the voltage applying means and a current flowing between the medium and the probe electrode to which the voltage has been applied by the voltage applying means satisfy current-voltage characteristics such that the current between the medium and the probe electrode also changes in accordance with a change in said applied voltage.

2. An apparatus according to claim 1, wherein the distance adjusting means adjusts the distance between the medium and the probe electrode so as to satisfy the relation which should be exhibited by the applied voltage and the current between the medium and the probe electrode in the case where a resistance characteristic between an electrode arranged on the lower side of the medium and the probe electrode doesn't change and the distance between the medium and the probe electrode is constant.

3. An apparatus according to claim 1, wherein the distance adjusting means has:

   current calculating means for calculating a current which should flow between the medium and the probe electrode in correspondence to the voltage applied by the voltage applying means;

   difference detecting means for detecting a difference between the current calculated by the current calculating means and an actual current flowing between the medium and the probe electrode; and

   driving means for driving at least one of the probe electrode and the medium so as to adjust the distance between the medium and the probe electrode on the basis of the difference detected by the difference detecting means.

4. An apparatus according to claim 1, wherein the distance adjusting means executes the adjustment so as to satisfy a resistance characteristic between an electrode arranged on the lower side of the medium and the probe electrode and the current-voltage characteristics which should be exhibited by the applied voltage and a tunnel current between the medium and the probe electrode in the case where the distance between the medium and the probe electrode is constant as said current characteristic.

5. An apparatus according to claim 1, wherein the distance adjusting means executes the adjustment so as to satisfy the resistance characteristic between an electrode arranged on the lower side of the medium and the probe electrode and the current-voltage characteristics which should be exhibited by the applied voltage and a field emission current between the medium and the probe electrode in the case where the distance between the medium and the probe electrode is constant as said current characteristic.

6. An apparatus according to claim 1, wherein the voltage applying means has:
a bias electric source to generate a bias voltage to detect the information from the medium;
signal generating means for generating a signal to record or erase the information onto/from the medium through the probe electrode; and
adding means for adding an output of the bias electric source and an output of the signal generating means and for applying between the medium and the probe electrode.

7. An apparatus according to claim 1, wherein the voltage applying means has:
a reproducing bias electric source to generate a bias voltage to reproduce the information;
a tracking bias electric source to generate a bias voltage for tracking; and
switching means for switching the bias voltage for reproducing and the bias voltage for tracking and for applying between the medium and the probe electrode.

8. An apparatus according to claim 1, wherein the voltage applying means has:
a DC bias electric source; and
bias modulating means for modulating a DC bias voltage generated from the DC bias electric source and for applying between the medium and the probe electrode.

9. An apparatus according to claim 8, further having synchronous detecting means for extracting a modulation component in the current between the medium and the probe electrode to which the voltage has been applied by the voltage applying means, and wherein a recording state is detected from said modulation component.

10. An apparatus for recording and/or reproducing information onto/from a medium through a probe electrode, comprising:
voltage applying means for applying a voltage between the medium and the probe electrode, in which the recording operation of the information onto the medium and/or the reproducing operation of the information from the medium are/is executed by applying the voltage by the voltage applying means; and
distance adjusting means for adjusting a distance between the medium and the probe electrode so as to keep constant a ratio of a current flowing between the medium and the probe electrode to which the voltage has been applied by the voltage applying means and the voltage applied by the voltage applying means.

11. An apparatus according to claim 10, wherein the distance adjusting means has:
current calculating means for calculating a current which should flow between the medium and the probe electrode in correspondence to the voltage applied by the voltage applying means;
difference detecting means for detecting a difference between the current calculated by the current calculating means and an actual current flowing between the medium and the probe electrode; and
driving means for driving at least one of the probe electrode and the medium so as to adjust the distance between the medium and the probe electrode on the basis of the difference detected by the difference detecting means.

12. An apparatus according to claim 10, wherein the voltage applying means has:
a bias electric source to generate a bias voltage to detect the information from the medium;
signal generating means for generating a signal to record or erase the information onto/from the medium through the probe electrode; and
adding means for adding an output of the bias electric source and an output of the signal generating means and for applying between the medium and the probe electrode.

13. An apparatus according to claim 10, wherein the voltage applying means has:
a reproducing bias electric source to generate a bias voltage to reproduce the information;
a tracking bias electric source to generate a bias voltage for tracking; and
switching means for switching the bias voltage for reproducing and the bias voltage for tracking and for applying between the medium and the probe electrode.

14. An apparatus according to claim 10, wherein the voltage applying means has:
a DC bias electric source; and

bias modulating means for modulating a DC bias voltage generated by the DC bias electric source and for applying between the medium and the probe electrode.

15. An apparatus according to claim 14, further having synchronous detecting means for extracting a modulation component in the current between the medium and the probe electrode to which the voltage has been applied by the voltage applying means, and wherein a recording state is detected from said modulation component.

16. An apparatus for recording and/or reproducing information onto/from a medium through a probe electrode, comprising:
voltage applying means for applying a voltage between the medium and the probe electrode, in which the recording operation of the information onto the medium and/or the reproducing operation of the information from the medium are executed by applying the voltage from the voltage applying means; and
distance adjusting means for adjusting a distance between the medium and the probe electrode in a manner such that a current I flowing between the medium and the probe electrode to which the voltage has been applied by the voltage applying means and an applied voltage V of the voltage applying means satisfy the following equation

$$I = C(V/Z_0)^2 \exp(-DZ_0/V)$$

where, C, D, and Z_0 are predetermined constants.

17. An apparatus according to claim 16, wherein the distance adjusting means has:
current calculating means for calculating a current which should flow between the medium and the probe electrode in correspondence to the voltage applied by the voltage applying means;
difference detecting means for detecting a difference between the current calculated by the current calculating means and an actual current flowing between the medium and the probe electrode; and
driving means for driving at least one of the probe electrode and the medium so as to adjust the distance between the medium and the probe electrode on the basis of the difference detected by the difference detecting means.

18. An apparatus according to claim 16, wherein the voltage applying means has:
a bias electric source to generate a bias voltage to detect the information from the medium;
signal generating means for generating a signal to record or erase the information onto/from the medium through the probe electrode; and
adding means for adding an output of the bias electric source and an output of the signal generating means and for applying between the medium and the probe electrode.

19. An apparatus according to claim 16, wherein the voltage applying means has:
a reproducing bias electric source to generate a bias voltage to reproduce the information;
a tracking bias electric source to generate a bias voltage for tracking; and
switching means for switching the bias voltage for reproducing and the bias voltage for tracking and for applying between the medium and the probe electrode.

20. An apparatus according to claim 16, wherein the voltage applying means has:
a DC bias electric source; and
bias modulating means for modulating a DC bias voltage generated from the DC bias electric source and for applying between the medium and the probe electrode.

21. An apparatus according to claim 20, further having synchronous detecting means for extracting a modulation component in the current between the medium and the probe electrode to which the voltage has been applied by the voltage applying means, and wherein a recording state is detected from said modulation component.

22. An apparatus for recording and/or reproducing information onto/from a medium through a probe electrode, comprising:
an electric source to apply a voltage between the medium and the probe electrode;

an information processing section for executing the recording operation and/or the reproducing operation of the information onto/from the medium in which the voltage has been applied between the probe electrode and the medium by the electric source;

an actuator to change a distance between the medium and the probe electrode; and

a servo circuit to control the actuator so as to keep constant a ratio of a current flowing between the medium and the probe electrode to which the voltage has been applied by the electric source and the voltage between the medium and the probe electrode.

23. An apparatus according to claim 22, wherein the servo circuit has:

a current calculating circuit to calculate a value of a current which should flow between the medium and the probe electrode in correspondence to the voltage between the medium and the probe electrode;

a subtracter to detect a difference between the logarithm of the current value calculated by the current calculating circuit and the logarithm of a value of an actual current flowing between the medium and the probe electrode; and

a command signal generating section to generate a command signal to the actuator on the basis of the difference detected by the subtracter.

24. An apparatus according to claim 23, wherein the information processing section has a current detector to detect the current between the medium and the probe electrode, the information is reproduced by the detection of the current detector, and the subtracter executes the subtraction between the logarithm of the current value calculated by the current calculating circuit and the logarithm of the current value detected by the current detector.

25. An apparatus according to claim 22, wherein the information processing section has:

a signal generator to generate a signal voltage to record or erase the information; and

an adder for adding the signal voltage generated from the signal generator and the voltage from the electric source and for applying between the medium and the probe electrode.

26. An apparatus for recording and/or reproducing information onto/from a medium through a probe electrode, comprising:

an electric source to apply a voltage between the medium and the probe electrode;

an information processing section to execute the recording operation and/or the reproducing operation of the information onto/from the medium in which the voltage has been applied between the probe electrode and the medium by the electrode source;

an actuator to change a distance between the medium and the probe electrode; and

a servo circuit to control the actuator in a manner such that a current I flowing between the medium and the probe electrode to which the voltage has been applied by the electric source and voltage V between the medium and the probe electrode satisfy the following equation

$$I = C(V/Z_0)^2 \exp(-DZ_0/V)$$

where C, D, and Z_0 are predetermined constants.

27. An apparatus according to claim 26, wherein the servo circuit has:

a current calculating circuit to calculate a value of a current which should flow between the medium and the probe electrode in correspondence to the voltage between the medium and the probe electrode;

a substracter to detect a difference between the logarithm of the current value calculated by the current calculating circuit and the logarithm of a value of an actual current flowing between the medium and the probe electrode; and

a command signal generating section to generate a command signal to the actuator on the basis of the difference detected by the subtracter.

28. An apparatus according to claim 27, wherein the information processing section has a current detector to detect the current between the medium and the probe electrode, the information is reproduced by the detection of the current detector, and the subtracter executes the subtraction between the logarithm of the current value calculated by the current calculating circuit and the logarithm of the current value

detected by the current detector.

29. An apparatus according to claim 26, wherein the information processing section has:
a signal generator to generate a signal voltage to record or erase the information; and
an adder for adding the signal voltage generated from the signal generator and the voltage from the electric source and for applying between the medium and the probe electrode.

30. An apparatus for recording and/or reproducing information onto/from a medium through a probe electrode, comprising:
voltage applying means for applying a voltage between the medium and the probe electrode, in which the recording operation of the information onto the medium and/or the reproducing operation of the information from the medium are/is executed by applying the voltage from the voltage applying means;
current detecting means for detecting a current flowing between the medium and the probe electrode to which the voltage has been applied by the voltage applying means; and
distance adjusting means for adjusting a distance between the medium and the probe electrode on the basis of the detection of the current detecting means, in which the distance adjusting means has correcting means for correcting a change amount of the current detected by the current detecting means due to a change in applied voltage of the voltage applying means and for executing the distance adjustment.

31. An apparatus according to claim 30, wherein the correcting means has:
current calculating means for calculating a current which should flow between the medium and the probe electrode in correspondence to the voltage applied by the voltage applying means; and
difference detecting means for detecting a difference between the current calculated by the current calculating means and an actual current flowing between the medium and the probe electrode,
and wherein the distance adjusting means has driving means for driving at least one of the probe electrode and the medium so as to adjust the distance between the medium and the probe electrode on the basis of the difference detected by the difference detecting means.

32. An apparatus according to claim 30, wherein the current detecting means detects a tunnel current flowing between the medium and the probe electrode.

33. An apparatus according to claim 30, wherein the current detecting means detects a field emission current flowing between the medium and the probe electrode.

34. An apparatus according to claim 30, wherein the voltage applying means has:
a bias electric source to generate a bias voltage to detect the information from the medium;
signal generating means for generating a signal to record or erase the information onto/from the medium through the probe electrode; and
adding means for adding an output of the bias electric source and an output of the signal generating means and for applying between the medium and the probe electrode.

35. An apparatus according to claim 30, wherein the voltage applying means has:
a reproducing bias electric source to generate a bias voltage to reproduce the information;
a tracking bias electric source to generate a bias voltage for tracking; and
switching means for switching the bias voltage for reproducing and the bias voltage for tracking and for applying between the medium and the probe electrode.

36. An apparatus according to claim 30, wherein the voltage applying means has:
a DC bias electric source; and
bias modulating means for modulating a DC bias voltage generated from the DC bias electric source and for applying between the medium and the probe electrode.

37. An apparatus according to claim 36, further having synchronous detecting means for extracting a modulation component in the current between the medium and the probe electrode to which the voltage has been applied by the voltage applying means, and wherein a recording state is detected from said modulation component.

38. A method of recording and/or reproducing information onto/from a medium through a probe electrode, comprising the steps of:

applying a voltage between the medium and the probe electrode, in which the recording operation of the information onto the medium and/or the reproducing operation of the information from the medium are/is executed by applying the voltage; and

adjusting a distance between the medium and the probe electrode in a manner such that the voltage applied in the voltage applying step and a current flowing between the medium and the probe electrode to which the voltage has been applied satisfy current-voltage characteristics such that the current between the medium and the probe electrode also changes in accordance with a change in said applied voltage.

39. A method of recording and/or reproducing information onto/from a medium through a probe electrode, comprising the steps of:

applying a voltage between the medium and the probe electrode, in which the recording operation of the information onto the medium and/or the reproducing operation of the information from the medium are/is executed by applying the voltage;

detecting a current flowing between the medium and the probe electrode to which the voltage has been applied; and

adjusting a distance between the medium and the probe electrode on the basis of the current detected in said current detecting step by correcting a change amount of the current detected in said current detecting step due to a change of the applied voltage.

40. An apparatus for recording and/or reproducing information onto/from a medium through a probe electrode, comprising:

voltage applying means for selectively applying either one of a first voltage and a second voltage whose absolute value is larger than that of the first voltage between the medium and the probe electrode in order to record and/or reproduce the information; and

distance control means for controlling a distance between the medium and the probe electrode in the case of applying the second voltage so as to approach the distance in the case where the first voltage has been applied.

41. An apparatus according to claim 40, wherein the distance control means has:

current calculating means for calculating a current which should flow between the medium and the probe electrode in correspondence to the voltage applied by the voltage applying means;

difference detecting means for detecting a difference between the current calculated by the current calculating means and an actual current flowing between the medium and the probe electrode; and

driving means for driving at least one of the probe electrode and the medium so as to adjust the distance between the medium and the probe electrode on the basis of the difference detected by the difference detecting means.

42. An apparatus according to claim 40, wherein the voltage applying means applies the first voltage to detect the information from the medium and applies the second voltage to record or erase the information onto/from the medium through the probe electrode.

FIG. 1

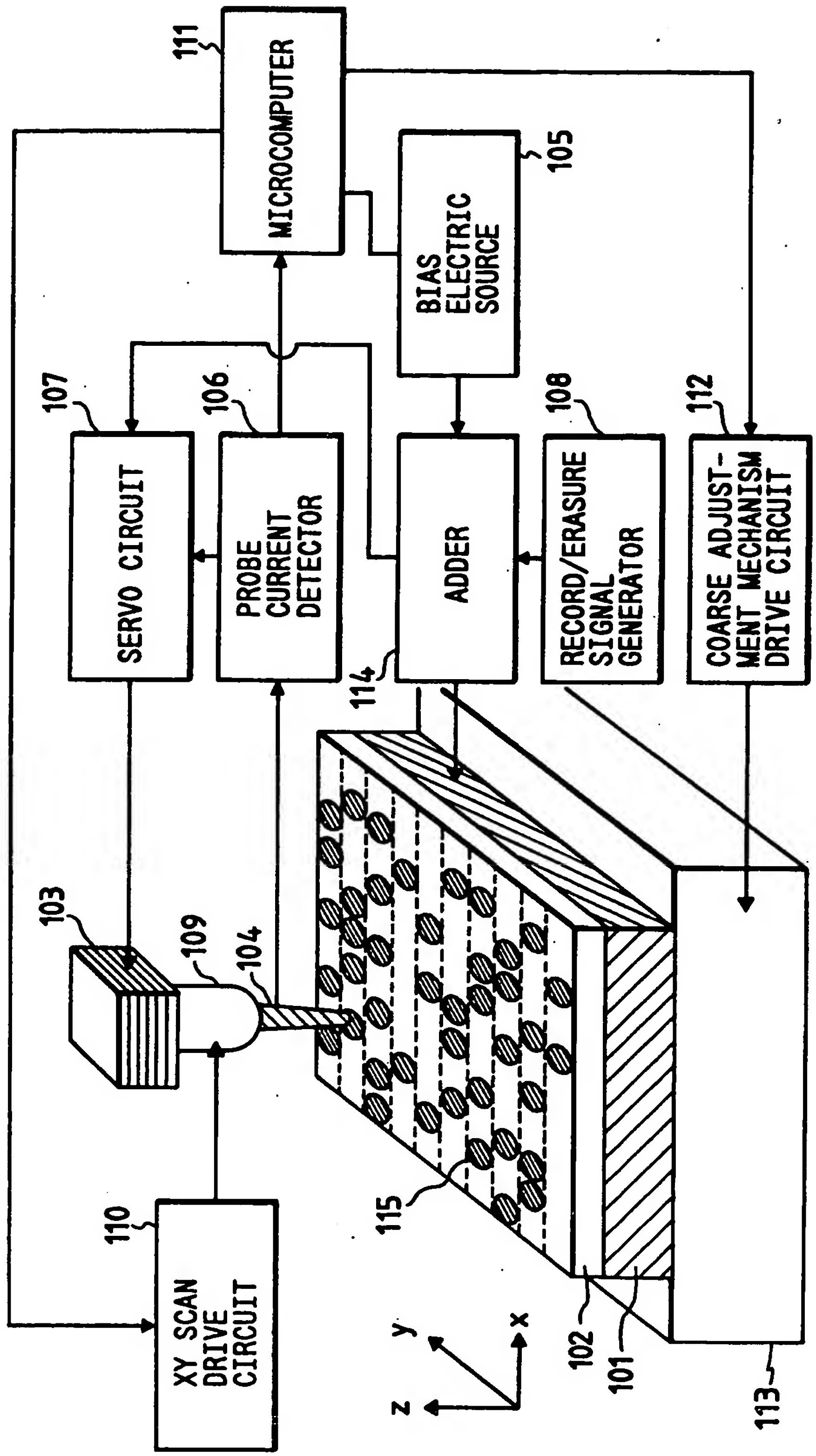

MICROCOMPUTER
111
BIAS ELECTRIC SOURCE
105
SERVO CIRCUIT
107
PROBE CURRENT DETECTOR
106
ADDER
114
RECORD/ERASURE SIGNAL GENERATOR
108
COARSE ADJUST-MENT MECHANISM DRIVE CIRCUIT
112
XY SCAN DRIVE CIRCUIT
110
103
109
104
115
102
101
113
x
y
z

FIG. 2

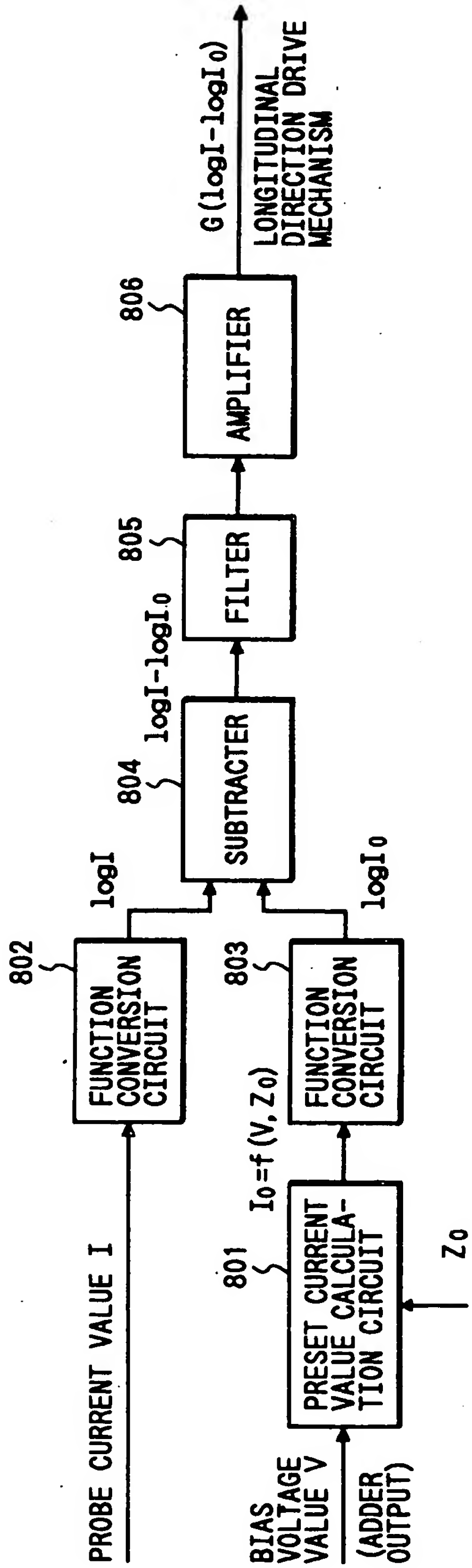

PROBE CURRENT VALUE I
BIAS VOLTAGE VALUE V
(ADDER OUTPUT)
801
PRESET CURRENT VALUE CALCULATION CIRCUIT
Zo
Io=f(V, Zo)
802
FUNCTION CONVERSION CIRCUIT
803
FUNCTION CONVERSION CIRCUIT
logI
logIo
804
SUBTRACTER
logI-logIo
805
FILTER
806
AMPLIFIER
G(logI-logIo)
LONGITUDINAL DIRECTION DRIVE MECHANISM

FIG. 3A

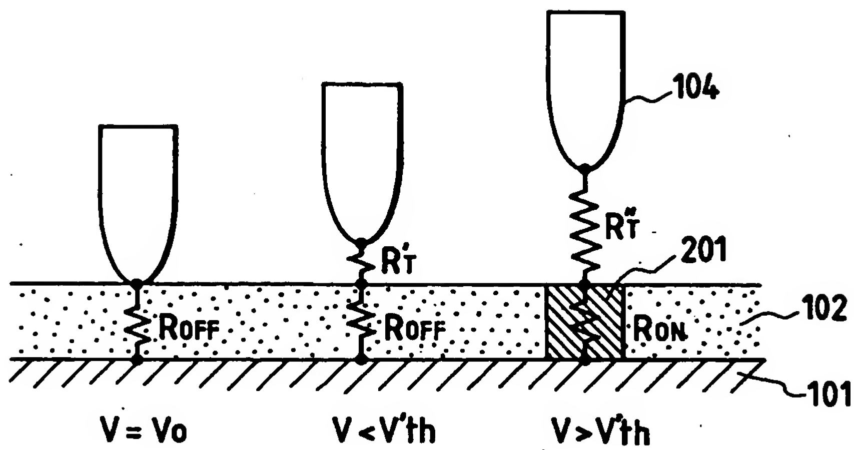

104
R'T
R''T
201
ROFF
ROFF
RON
102
101
V = Vo
V < V'th
V > V''th

FIG. 3B

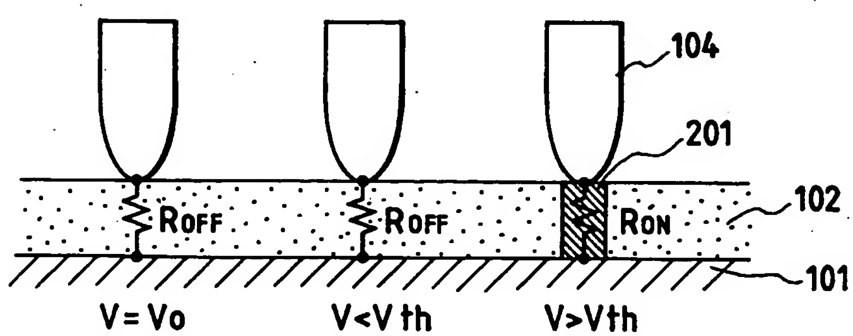

104
201
ROFF
ROFF
RON
102
101
V = Vo
V < V th
V > V th

FIG. 4A

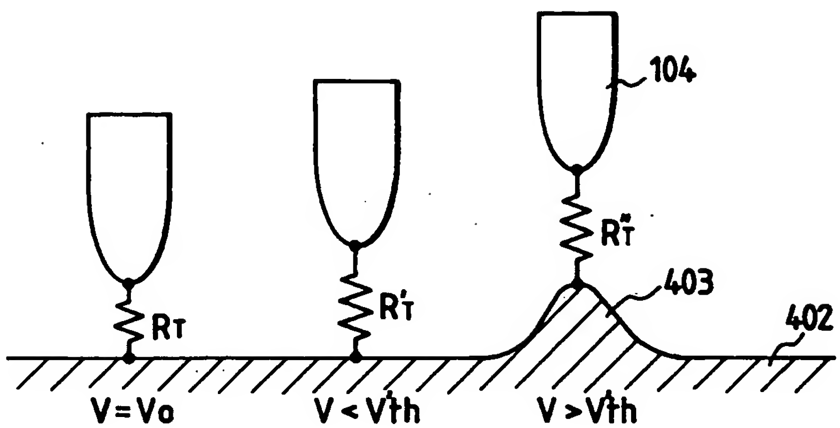

104
RT
R'T
R"T
403
402
V=Vo
V<V'th
V>V'th

FIG. 4B

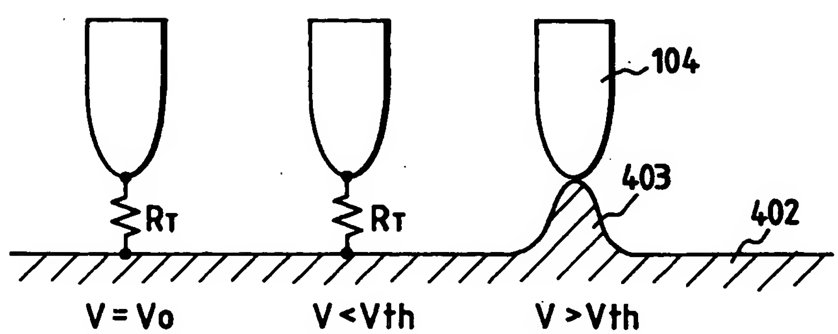

104
RT
RT
403
402
V=Vo
V<Vth
V>Vth

FIG. 5

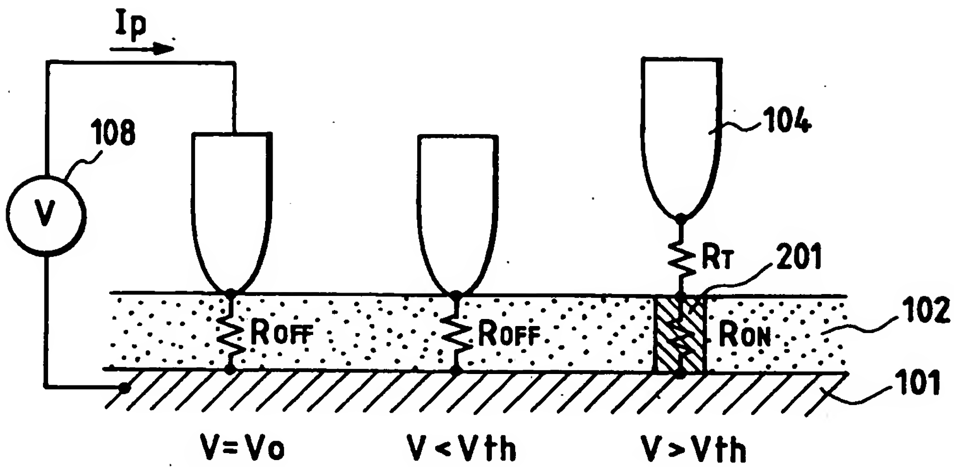

Ip
108
V
104
RT
201
ROFF
ROFF
RON
102
101
V=Vo
V<Vth
V>Vth

FIG. 6

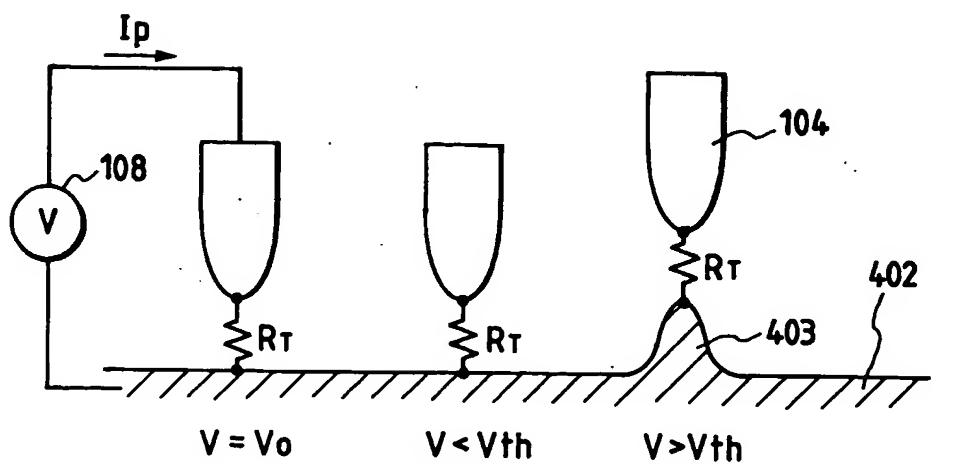

Ip
108
V
104
RT
RT
RT
402
403
V = Vo
V<Vth
V>Vth

FIG. 7

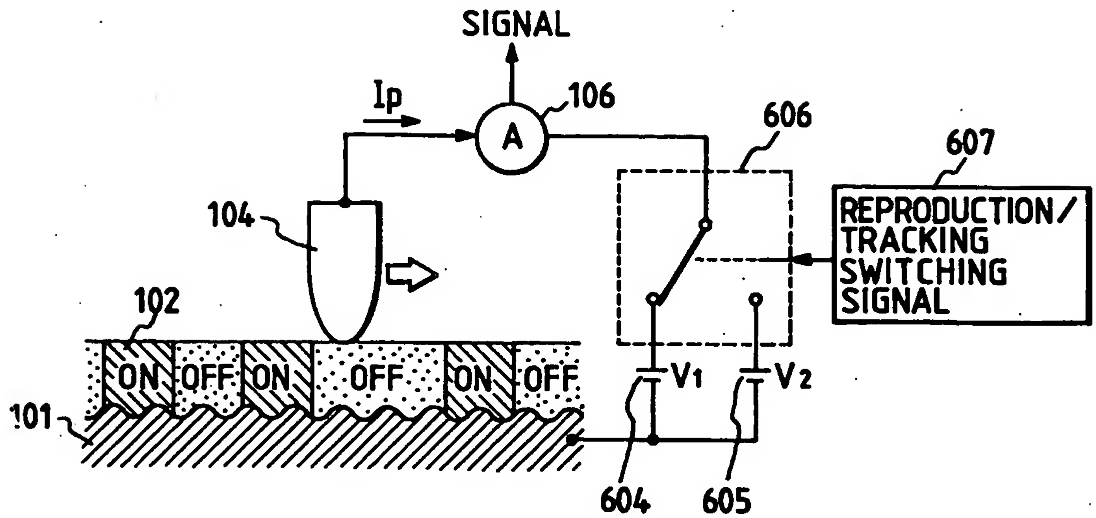
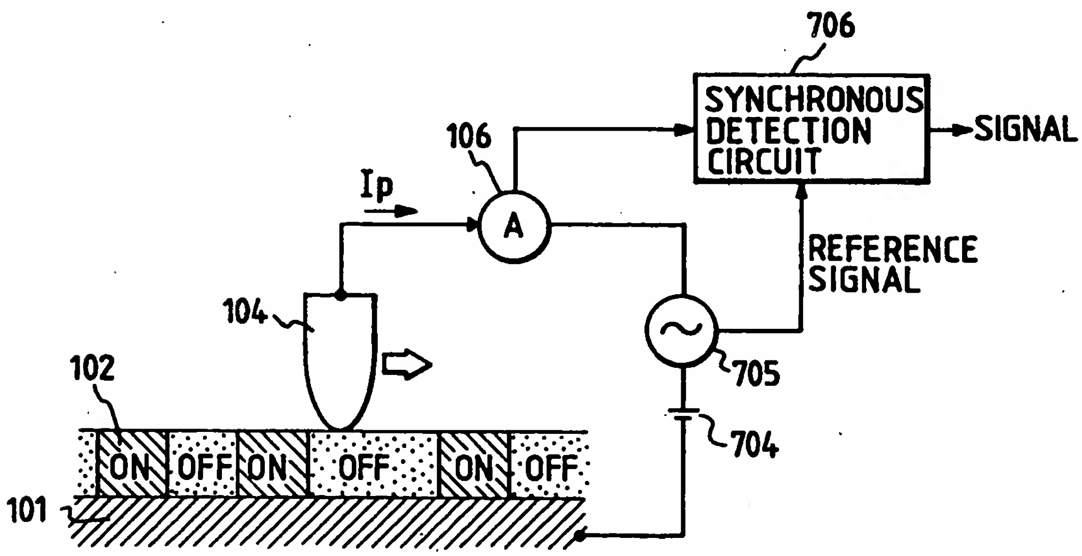

SIGNAL
Ip
A
106
606
607
REPRODUCTION/
TRACKING
SWITCHING
SIGNAL
104
102
ON
OFF
ON
OFF
ON
OFF
101
V1
V2
604
605

FIG. 8


706
SYNCHRONOUS
DETECTION
CIRCUIT
SIGNAL
106
Ip
A
REFERENCE
SIGNAL
104
102
705
704
ON
OFF
ON
OFF
ON
OFF
101